The Cold Factor

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Figure 2. Windchill and wind speed.

Figure 3. Effect of snowfall on manual and equipment tasks.

ALMOST any kind of outdoor work requires more time and effort when performed in a cold environment, the principal characteristics of which are low temperature, wind, and precipitation (snowfall). Comparative field tests, where the only variables are the environmental conditions, while the tasks, equipment, and personnel remain the same, would provide relatively reliable data on the effects of the environment. In the absence of such data, it is necessary to use the available results of surveys from the construction industry and the military, which indicate the relative efficiency of people and equipment while functioning in selected cold environment conditions. The following analysis represents an initial attempt to predict the influence of cold environment on outdoor work by introducing a "cold environment factor," the inverse of efficiency.
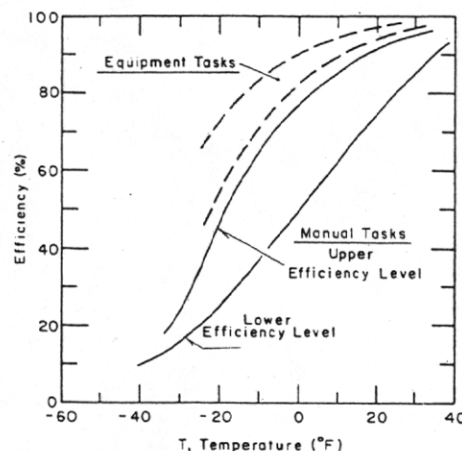

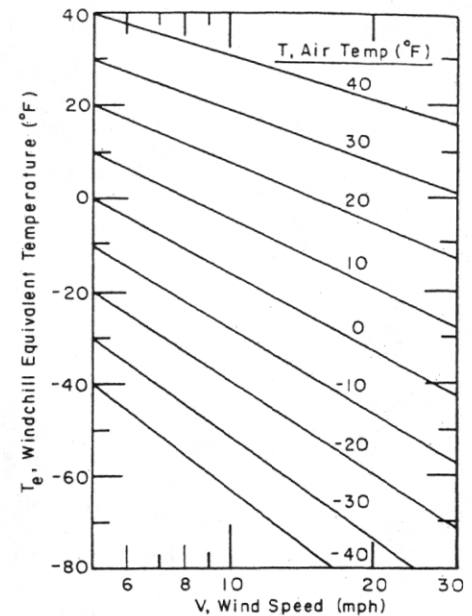Figure 1. The effects of temperature in a cold environment.
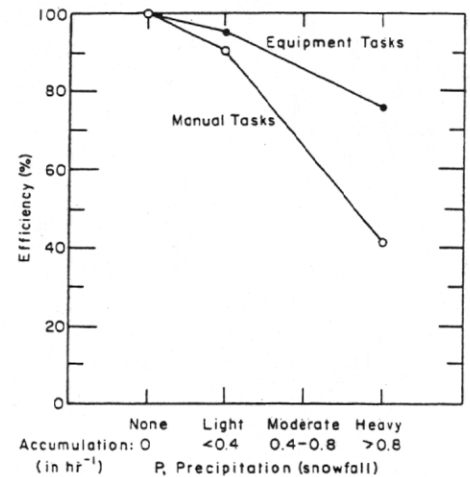
Effect of temperature, wind, and snowfall

Figure 1 shows the typical range of efficiency for construction or repair types of manual and equipment tasks as a function of air temperature. The upper curve of the manual task envelope in Figure 1 could be considered the upper efficiency level, with the lower curve representing the lower level. Below -40°F any manual work becomes extremely difficult, regardless of motivation or experience. At this temperature construction equipment is rarely operated. Data from surveys show that the variation in efficiency of a particular piece of equipment or a task at a specific weather condition is much wider than the variation between
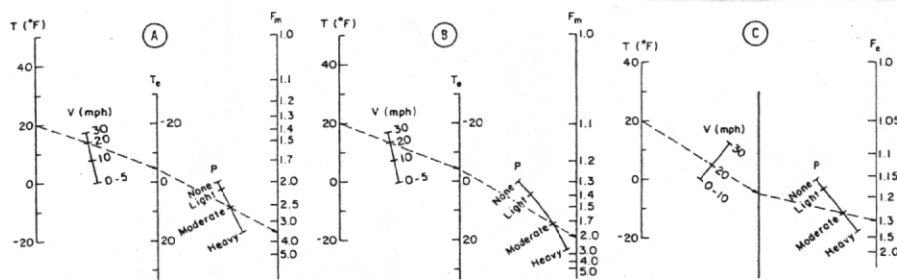
Figure 4. Nomographs for estimating cold environment tasks. A is for manual tasks (lower efficiency), B (upper efficiency), and C is for equipment tasks.

several types of equipment. Therefore, at this time, no distinction is made between specific types of tasks or equipment.

There is a general lack of published data on the effects of wind. For manual tasks, the wind influence can be expressed by the "windchill factor" which combines the effects of both temperature and wind on humans. The general empirical equation to measure windchill, developed by Paul Sipe 50 years ago in Antarctica, is:
$$Te=91.4-[(0.288\sqrt{V}+0.45-0.019V)(91.4-T)] \text{ where:}$$
Te=equiv. windchill temp. (°F)
V=wind speed (mph)
T=air temperature (°F)

The equation is applicable only for the wind speed range between 5 and 50 mph. For the range of $5<V<30$, the windchill can be computed more conveniently by:
$$Te=\log V(0.59T-54.2)+0.59T+37.2$$
The relationship between windchill and wind speed at various air temperatures is shown in Figure 2.

The windchill factor cannot be applied to equipment. Available data show equipment efficiency to be in the 80 to 90 percent range at a wind speed of 30 mph, requiring interpolation for lower speeds.

The effect of snowfall intensity (which incorporates visibility, accumulation problems, etc.) on manual and equipment tasks is shown in Figure 3.

The cold factor

To express the relative effort of performing a construction or a repair task in cold weather, it is more convenient to use a factor that is the inverse of efficiency (F=1/E), the base value (F=1) representing the effort required to perform the task under ideal weather conditions (temperature 50 to 60°F for manual tasks, 40°F or above for

equipment tasks, no wind or precipitation). As work efficiency decreases with the adversity of weather conditions, the "cold environment factor" increases, giving the value by which the optimum work effort (in terms of time) would have to be multiplied to determine the length of time required to perform a particular task.

From the efficiency data, nomographs have been constructed showing the "cold environment factors" for manual (Fm) and equipment tasks (Fe) at any temperature, wind, and snowfall condition (Figure 4).

The factor for manual tasks is

Environmental Conditions			Cold Environment Factor	
T (°F)	Wind (mph)	Snow-fall	Fm (Manual)	Fe (Equipm.)
20	<5	O	1.1	1.05
20	<5	L	1.2	1.10
20	<5	M	1.7	1.24
20	<5	H	2.8	1.40
10	<5	O	1.2	1.09
10	<5	L	1.3	1.14
10	<5	M	1.8	1.29
10	<5	H	3.0	1.45
0	<5	O	1.3	1.16
0	<5	L	1.45	1.22
0	<5	M	2.0	1.37
0	<5	H	3.3	1.54
-10	<5	O	1.5	1.28
-10	<5	L	1.7	1.34
-10	<5	M	2.4	1.51
-10	<5	H*	3.7	1.70
-20	<5	O	2.0	1.54
-20	<5	L	2.3	1.62
-20	<5	M*	3.0	1.82
-20	<5	H*	5	2.05
20	20	O	1.4	1.10
20	20	L	1.6	1.16
20	20	M	2.2	1.30
20	20	H	3.5	1.47
10	20	O	2.0	1.14
10	20	L	2.2	1.20
10	20	M	2.6	1.35
10	20	H	4	1.52
0	20	O	>5	1.22

Table 1. Cold environment factors in various weather conditions. *Snowfall of this intensity at this temperature very unlikely.

shown for both the lower and upper efficiency levels (Figures 4a and 4b, respectively). For equipment performance, the mean values from Figure 1 were used to construct the nomograph (Figure 4c).

The example shown in Figure 4 (T=20°F, V=20 mph, P=moderate snowfall) indicates that, for this condition, the standard time for each manual task would have to be multiplied by 2.2, assuming upper efficiency level (or by 3.6 for the lower efficiency level), and the time for any equipment task by 1.3.

The factors for the manual (upper efficiency level) and equipment tasks for various environmental conditions are shown in Table 1.

A typical military application of the "cold environment factor" scheme would be, for example, in the development of rapid runway repair procedures, where time is a critical element. When Program Evaluation Review Techniques (PERT) diagrams are eventually developed showing the "critical path" for repair procedures during ideal weather conditions, it will be necessary to predict the expected cold environment effects on the schedule. The introduction of the "cold environment factors" will result in a stretched PERT diagram, an important consideration being the effect on the "critical path."

The effect on activities where manual and equipment tasks are integrated, or cannot be separated, remains to be investigated.

At this stage, the "cold environment factor" scheme, described here, is merely a first attempt to predict the likely effect of a cold environment on construction and repair efforts. Actual field tests are required to determine if and how the "cold environment factors" need to be modified.